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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
CORADCOM- 79-0789-6A

MANUFACTURING METHODS AND TECHNOLOGY PROGRAM FOR RUGGEDIZED TACTICAL FIBER OPTIC CABLE

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SIXTH PROGRESS REPORT
FOR PERIOD
APRIL, 1981 - JUNE, 1981

APPROVED FOR PUBLIC RELEASE ; DISTRIBUTION UNLIMITED

CORADCOM
US ARMY COMMUNICATION RESEARCH & DEVELOPMENT COMMAND
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This project has been accomplished as part of the U.S. Army Manufacturing Methods and Technology Program which has as its objective the timely establishment of manufacturing processes, techniques, or equipment to insure the efficient production of current or future defense programs.

MANUFACTURING METHODS AND TECHNOLOGY PROGRAM

FOR RUGGEDIZED TACTICAL FIBER OPTIC CABLE

SIXTH PROGRESS REPORT

Contract DAAK80-79-C-0789

For the Period April 1981-June 1981

Object of Study:
To Establish an Automated Production
Process for Ruggedized Tactical
Fiber Optic Cable

Approved for public release; distribution unlimited.

Prepared for:

U.S. Army Communications
Research and Development Command
Procurement Directorate, Procurement Division D
Fort Monmouth, New Jersey 07703

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Fiber and Cable

Date: September 24, 1981
Doc Id No: 81-38-03a

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CORADCOM-79-0789-6A	2. GOVT ACCESSION NO. AD-A120779	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MANUFACTURING METHODS AND TECHNOLOGY PROGRAM FOR RUGGEDIZED TACTICAL FIBER OPTIC CABLE		5. TYPE OF REPORT & PERIOD COVERED Sixth Progress Report April 1981 - June 1981
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. Smith		8. CONTRACT OR GRANT NUMBER(s) DAAK80-79-C-0789
9. PERFORMING ORGANIZATION NAME AND ADDRESS ITT Electro-Optical Products Division 7635 Plantation Road, N.W. Roanoke, Virginia 24019		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Communications Research and Development Command Procurement Directorate, Procurement Division D ATTN: DRDCO-PC-D, Ft. Monmouth, New Jersey 07703		12. REPORT DATE September 1981
		13. NUMBER OF PAGES 44
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fiber Optic Cable, Fiber Optic Communications
Fiber Optic, Tactical Fiber Optic Cable

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers the period from April 1981 through June 1981 of the manufacturing methods and technology program for ruggedized tactical fiber optic cable. The scope of this effort, as reported herein, includes the following tasks and achievements in materials selection:

20. (continued)

a. Selection of polyurethane compound,

b. Evaluation of selected compound,

(1) Mechanical performance (impact resistance, twist-bend, and flexure tests)

(2) Mechanical performance at the temperature extremes (-55°C and +71°C)

c. Fabrication of long cables for mechanical evaluation at room temperature, at -55°C and at +71°C, and optical evaluation at room temperature and at -55°C, AND

d. Recommendation of a polyurethane compound for the cable MM&T program.

SUMMARY

This report covers the period from April 1 to June 30, 1981, of the manufacturing methods and technology (MM&T) program for a ruggedized tactical fiber optic cable.

During this time frame, an intensive study of polyurethane jacketing compounds was completed. This study was needed because the original compound manufacturer sold the polyurethane business line and the buyer had some difficulties reproducing the original jacketing compound. In parallel to this effort ITT EOPD conducted an internally funded polyurethane evaluation program which resulted in the selection of two new compounds. The polyurethane jacket compound study had to be completed prior to the fabrication and evaluation of 12 confirmatory sample cables to ensure compliance with specification MM&T-789898. Optical fibers with a numerical aperture (NA) of 0.25 ±0.03 were selected for cable construction because of their better low temperature performance. Two cables for the confirmatory sample phase were stranded.

PREFACE

The purpose of this MM&T program is to establish automated production processes for ruggedized tactical fiber optic cables in accordance with specification MM&T-789898 dated 2 February 1978, with Revision 1 dated 1 August 1980, and ECIPPR 15.

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1.0 INTRODUCTION

This document describes the results of the MM&T cable development, which includes fiber and materials evaluation, and optimization of low and high temperature fiber and cable performance during the second quarter of 1981.

The purpose of this contract is to establish automated production processes for ruggedized tactical fiber optic cables. In the period covered by reports 1 through 5, the initial stages of cable fabrication, facilities operation, materials evaluation, first attempt at fabrication of confirmatory samples, testing of production rates for the high speed strander, fiber serving line, jacket extrusion lines, and evaluation of the test stations were described. During this period, it was requested that low temperature performance be monitored. As a result, it was determined that lower NA fibers did not give a suitable attenuation performance at low temperature. Additionally, it was discovered that previously satisfactory polyurethane did not meet performance requirements as a result of formula and processing changes made when the product line was purchased by another manufacturer.

As a result, studies of low temperature attenuation performance, development of higher NA fibers, and evaluation of replacement polyurethanes were undertaken.

In this report the polyurethane selection, including the effects on cable properties due to processing temperatures, are described. The evaluation of the jacketing compound, including impact resistance test, twist-flex test, and flexure test at room temperature (~+25°C), -55°C, and +71°C are discussed.

The goals for the next period are

a. Obtain CECOM approval of the selected polyurethane

b. Incorporate the polyurethane change into the confirmatory samples

c. Fabricate 12 confirmatory sample cables

d. Evaluate cables and deliver them to CECOM

2.0 POLYURETHANE EVALUATION

This report presents in one document the complete polyurethane evaluation. Part of the information presented was described in the fifth quarterly report.

The engineering samples were fabricated using Roylar® E-80 supplied by Uniroyal Chemical, Inc., which sold its trade name and product line to B.F. Goodrich. ITT Electro-Optical Products Division (EOPD) evaluated the compound produced by B.F. Goodrich (its new name is Estane® 58880) and found that its performance differed considerably from Uniroyal's Roylar® E-80.

Table 2.0-1 shows the mechanical characteristics of Roylar® E-80, two modified versions fabricated by B.F. Goodrich, and Estane® 58309.

2.1 Selections of Estane® 58309 for the Cable MM&T Program

It must be noted that the two modified versions were made by B.F. Goodrich when the original formulation of Roylar® E-80 failed in the mechanical tests. This was an attempt to determine if the melt index number had an effect on the desired mechanical characteristics. Since this approach did not promise a rapid solution to the jacketing problem, it was decided to investigate Estane® 58309, which was previously preselected for the standard ITT EOPD commercial cables.

Table 2.0-1. Characteristics of Polyurethane Compounds.

	Original Roylar® E-80	First Modification E-80 Estane® 4054BL-4	Second Modification E-80 Estane® 4054BL-19	Estane® 58309
Durometer hardness	82A	80A	84A	85A
Ultimate tensile strength, psi	4100	4400	4000	5900
Ultimate elongation, %	735	700	700	560
Tensile modulus, psi (300%)	1100	1100	1500	1750
Tear strength, pli	480	470	515	550
Vicant softening point	+83°C	+84°C	+98°C	+101°C
Gehman freeze point	-55.5°C	-54.8°C	-48.5°C	-52°C
Gehman twist angle	165°	168°	163°	NA*
Gehman modulus of rigidity				
T_2 value	-35.5°C	-34.5°C	-32.5°C	-22°C
T_5	-41.2°C	-40.6°C	-39.5°C	-33°C
T_{10}	-44.7°C	-43.8°C	-41.0°C	-38°C
T_{50}	-53.7°C	-52.0°C	-52.5°C	-57°C
T_{100}	-75.0°C	-60.0°C	-61.0°C	NA
Melt index (+190°C, 8700 g)	15.0	30	3	35

*NA - not available.

The major differences are

a. Estane● 58309 is slightly harder than Roylar● E-80 (Shore A = 85 versus 82)

b. Estane● 58309 has a higher modulus and tensile strength

c. Estane● 58309 has a superior tear resistance

d. Estane● 58309 has a higher melt index number

Estane● 58309 was selected for ITT EOPD's commercial application after comparing its performance to Roylar● E-9 and Estane● 4038 (Estane● 4038 was the laboratory batch of Roylar● E-9 made by B.F. Goodrich) and to Estane● 58311. Table 2.1-1 shows that Estane● 58309 and Estane● 58311 performed identically. Estane● 58309, however, was selected because it can be obtained in black color and in uniform size pellets while Estane● 58311 can only be obtained in natural color and in irregular size chips. Irregular chips cause feed problems in the 1 1/2 in extruder that ITT EOPD is using for cable jacketing, i.e., the extrudate can flow unevenly from the extruder which causes cable diameter fluctuations and cone breaks.

Table 2.1-2 shows that cables extruded with Roylar● E-9B and Estane● 4038 have fiber breaks due to the radial cracks that occur during the low temperature twist-bend test; however, no failures were observed during impact testing. Cables jacketed with Estane● 58311 passed impact tests whereas cables jacketed with Estane●

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Table 2.1-1. Polyurethane Jacket Evaluation.

Cable Jacket Material	Twist-Bend # Passed/# Tested			Bend # Passed/# Tested			Impact # Passed/# Tested		
	-55°C	Room Temp	+72°C	-55°C	Room Temp	+72°C	-55°C	Room Temp	+72°C
Roylar● E-9B (No 071480-4C-1B)	1/3	3/3	Not tested	3/3	3/3	Not tested	Not tested	6/6	6/6
Estane● 58311 (No 071480-4C-1)	3/3	3/3	3/3	3/3	3/3	3/3	6/6	6/6	6/6
Estane● 58309-021 (No 082379-Z1)	3/3	3/3*	3/3	3/3	3/3	3/3	6/6	6/6	6/6
Estane● 4038 (No 082379-Z2)	0/3	3/3*	3/3	3/3	3/3	3/3	6/6	6/6	6/6

*One sample had Kevlar● bunching over in the area of the pulley during the run.

58309 exhibited broken fibers during impact tests. It was determined, however, that fiber breakage during impact testing was due to the incorporation of mechanically weaker fibers as compared to standard strong fiber.

To further confirm Estane® 58309 as the best cable jacket material, the following two steps were initiated:

a. Build samples with different lot numbers of Estane® 58309 and explore higher, lower, and standard extruder temperature profile

b. Jacket two confirmatory sample cables with Estane® 58309 to determine the effect of the polyurethane compound on low temperature attenuation of cabled fibers

2.2 Evaluation of Estane® 58309

Five 200-m to 300-m cables were fabricated as follows:

a. Three cables were jacketed with polyurethane from different lot numbers

The purpose of this evaluation was to determine if Estane® 58309 coming from different lots still meets the MM&T-789898 specification. In addition, the black compound has three digits (example: Estane® 58309 BLK 288 or Estane® 58309 BLK 289). Since it was learned that the last three digits represented a different process as to how the compound was made black, it was necessary to investigate its potential effect in the mechanical performance of the cable.

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Table 2.1-2. Polyurethane Evaluation (Fiber Breakage).

Cable Jacket Material	Twist-Bend # Fibers Not Transmitting			Bend # Fibers Not Transmitting			Impact # Fibers Not Transmitting		
	-55°C	Room Temp	+72°C	-55°C	Room Temp	+72°C	-55°C	Room Temp	+72°C
Royslar® E-9B (No 071480-4C-1B) (6 fibers)	3*	0	Not tested	0	0	Not tested	Not tested	0	0
Estane® 58311 (No 071480-4C-1) (6 fibers)	0	0	0	0	0	0	0	0	0
Estane® 58309-021 (No 082379-Z1) (7 fibers)	0	0	0	0	0	0	0	9**	2***
Estane® 4038 (No 082379-Z2) (7 fibers)	3,1,2****	0	1	0	0	0	0	2*	1

*In one sample.
**At least one in each sample.
***Central fibers in two samples.
****In samples 1, 2, and 3, respectively.

Another factor that may have an effect on mechanical performance was the processing condition during the extrusion of polyurethane. Since it is not possible, within the scope of this evaluation, to investigate all processing conditions, it was determined that temperature was the most important parameter; therefore, one of the selected batches of polyurethane was extruded at +20°F lower than standard, at standard, and +20°F above standard temperature. It was judged that +20°F above or below standard temperature would still yield a good cable.

Table 2.2-1 shows the impact resistance at a 3 ft•lb load of the five samples. The impact test was performed in accordance with DOD-STD-1678 and the testing temperatures were room temperature, -55°C, and +71°C.

The impact test caused several fibers to break at -55°C. The lowest fiber survivability was rated at 80%; however, there was no jacket split.

Since an earlier agreement limited the low temperature impact to 2.25 ft•lb, impact tests were subsequently performed at that level to determine what improvement in fiber survivability can be achieved by lowering the impact load.

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Table 2.2-1. MM&T Cables - Impact Resistance: 3 ft·lb Load.

Cable	Room Temperature				-55°C				+71°C			
	#S	#BF	%SF	JS	#S	#BF	%SF	JS	#S	#BF	%SF	JS
58309 BLK 289 590002 Low temperature	6	0	100	0	6	3	92	0	6	1	97	0
Medium temperature	6	1	97	0	6	2	94	0	6	0	100	0
High temperature	6	0	100	0	5	6	80	0	6	0	100	0
58309 BLK 288 900917 Low temperature	6	0	100	0	-	Not tested		-	6	0	100	0
58309 BLK 289 590003 Low temperature	6	0	100	0	6	7	81	0	6	0	100	0

#S = No of samples tested

#BF = No of broken fibers

%SF = Percent of surviving fibers = $\frac{\#S \times 6 - \#BF}{\#S \times 6} \times 100$

S = Jacket splits

Tables 2.2-2 through 2.2-4 show the room temperature, -55°C, and +71°C impact resistance. There was not one single case of jacket split. The worst case of broken fibers is shown in Table 2.1-2 where the -55°C test of the Estane® 58309, BLK 289 lot number 590003, had five broken fibers.

Table 2.2-5 summarizes the impact resistance at room temperature, -55°C, and +71°C with loads from 3.0 ft•lb down to 2.25 ft•lb.

This extensive series of tests proved that the compound Estane® 58309 was a good choice for the MM&T program because there were no jacket splits and fibers incorporated into these short cable samples were fibers previously rejected for not meeting the 100,000 psi proof-test. Therefore, a high probability existed that fiber breakage during impact testing was caused by micro-cracks on the fiber surface.

Table 2.2-6 shows the twist-bend test, which was performed in accordance with DOD-STD-1678. The mandrel diameter was five times the cable diameter (3.175 cm or 1.25 in).

Surprisingly, a large number of samples failed the low temperature twist-bend test. Numerous radial cracks destroyed the outer jacket resulting in some broken fibers. This problem was unexpected since during preliminary evaluation of Estane® 58309 all samples passed.

Table 2.2-2. MM&T Cables - Impact Resistance: 2.75 ft·lb Load.

Cable	Room Temperature				-55°C				+71°C			
	#S	#BF	%SF	JS	#S	#BF	%SF	JS	#S	#BF	%SF	JS
58309 BLK 289 590002 Low temperature	6	0	100	0	6	1	97	0	6	0	100	0
Medium temperature	-	-	-	-	-	-	-	-	-	-	-	-
High temperature	-	-	-	-	-	-	-	-	-	-	-	-
58309 BLK 288 900917 Low temperature	-	-	-	-	-	-	-	-	-	-	-	-
58309 BLK 289 590003 Low temperature	6	0	100	0	6	5	86	0	6	0	100	0

#S = No of samples tested

#BF = No of broken fibers

%SF = Percent of surviving fibers = $\frac{\#S \times 6 - \#BF}{\#S \times 6} \times 100$

JS = Jacket splits

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Table 2.2-3. MM&T Cables - Impact Resistance: 2.5 ft·lb Load.

Cable	Room Temperature				-55°C				+71°C			
	#S	#BF	%SF	JS	#S	#BF	%SF	JS	#S	#BF	%SF	JS
58309 BLK 289 590002 Low temperature	6	0	100	0	6	2	94	0	6	0	100	0
Medium temperature	-	-	-	-	-	-	-	-	-	-	-	-
High temperature	-	-	-	-	-	-	-	-	-	-	-	-
58309 BLK 288 900917 Low temperature	-	-	-	-	-	-	-	-	-	-	-	-
58309 BLK 289 590003 Low temperature	6	0	100	0	6	2	94	0	6	0	100	0

#S = No of samples tested

#BF = No of broken fibers

%SF = Percent of surviving fibers = $\frac{\#S \times 6 - \#BF}{\#S \times 6} \times 100$

JS = Jacket splits

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Table 2.2-4. MM&T Cables - Impact Resistance: 2.25 ft·lb Load.

Cable	Room Temperature				-55°C				+71°C			
	#S	#BF	%SF	JS	#S	#BF	%SF	JS	#S	#BF	%SF	JS
58309 BLK 289 590002 Low temperature	6	0	100	0	6	0	100	0	6	0	100	0
Medium temperature	-	-	-	-	-	-	-	-	-	-	-	-
High temperature	-	-	-	-	-	-	-	-	-	-	-	-
58309 BLK 288 900917 Low temperature	-	-	-	-	-	-	-	-	-	-	-	-
58309 BLK 289 590003 Low temperature	6	0	100	0	6	1	97	0	6	0	100	0

#S = No of samples tested

#BF = No of broken fibers

%SF = Percent of surviving fibers = $\frac{\#S \times 6 - \#BF}{\#S \times 6} \times 100$

JS = Jacket splits

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Table 2.2-5. MM&T Cables - Impact Test Summary.

Estane® 58309 BLK 289

Lot #3590002

Medium temperature

Impact load	Room Temperature				-55°C				+71°C			
	#S	#BF	%SF	JS	#S	#BF	%SF	JS	#S	#BF	%SF	JS
3 ft•lb	6	1	97	0	6	2	94	0	6	0	100	0
2.75 ft•lb	6	0	100	0	6	0	100	0	6	0	100	0
2.50 ft•lb	6	0	100	0	6	2	94	0	6	0	100	0
2.25 ft•lb	6	0	100	0	6	0	100	0	6	0	100	0

#S = No of samples tested

#BF = No of broken fibers

%SF = Percent of surviving fibers = $\frac{\#S \times 6 - \#BF}{\#S \times 6} \times 100$

JS = Jacket splits

Table 2.2-6. MM&T Cables - Twist-Bend Test: 1.25 in Mandrel (Samples With Slight Slack).

Cable	Room Temperature				-55°C				+71°C			
	#S	#BF	%SF	JS	#S	#BF	%SF	JS	#S	#BF	%SF	JS
58309 BLK 289 590002 Low temperature	6	0	100	0	6	2	94	5	6	0	100	0
Medium temperature	6	0	100	0	6	0	100	3	6	0	100	0
High temperature	6	0	100	0	6	2	94	5	6	0	100	0
58309 BLK 288 900917 Low temperature	6	0	100	0	6	1	97	3	6	0	100	0
58309 BLK 289 590003 Low temperature	6	0	100	0	5	0	100	5	6	0	100	0

#S = No of samples tested

#BF = No of broken fibers

%SF = Percent of surviving fibers = $\frac{\#S \times 6 - \#BF}{\#S \times 6} \times 100$

JS = Jacket splits

There was no problem in meeting the twist-bend test at room temperature and at +71°C. Since DOD-STD-1678 does not clearly state how to secure the cable during the twist-bend test, ITT EOPD investigated the clamping method by testing the cable with a slight slack and prestressed. The majority of the samples clamped with a slight slack developed radial cracks and some broken fibers as seen in Table 2.2-6. The prestressed samples passed the test; no jacket cracks or broken fibers were developed as shown in Table 2.2-7.

It was observed that the samples with slight slack had a whipping action across the mandrel causing jacket splits and fiber breakage. It was also observed that if the mandrel diameter is increased to 7.62 cm or 3.0 in (12 times cable diameter) there will be no cracks or fiber failures even with slack in the clamped cable. See Table 2.2-8.

The results of the flexure test, per DOD-STD-1678, are shown in Table 2.2-9. All samples passed the test at room temperature, at -55°C, and at +71°C.

2.3 Evaluation of Long Cables With Estane® 58309 Jackets

The five cable samples used for the testing described in paragraph 2.2 were short (200 m-300 m) and were made with fibers that did not meet the optical and/or proof-test requirements of the MM&T fibers. Rejected fibers were chosen for short sample preparation

Table 2.2-7. MM&T Cables - Twi. -Bend Test at -55°C, 1.25 in Mandrel (Prestressed Samples).

Cable	Room Temperature				-55°C				+71°C			
	#S	#BF	%SF	JS	#S	#BF	%SF	JS	#S	#BF	%SF	JS
58309 BLK 289 590002 Low temperature	-	-	-	-	6	0	100	1*	-	-	-	-
Medium temperature	-	-	-	-	-	-	-	-	-	-	-	-
High temperature	-	-	-	-	-	-	-	-	-	-	-	-
58309 BLK 288 900917 Low temperature	-	-	-	-	6	0	100	0	-	-	-	-
58309 BLK 289 590003 Low temperature	-	-	-	-	6	0	100	0	-	-	-	-

#S = No of samples tested

#BF = No of broken fibers

%SF = Percent of surviving fibers = $\frac{\#S \times 6 - \#BF}{\#S \times 6} \times 100.$

JS = Jacket splits

*Cable system <u>not</u> prestress.

Table 2.2-8. MM&T Cables - Twist-Bend Test: 3.0 in Mandrel.

Cable	Room Temperature				-55°C				+71°C			
	#S	#BF	%SF	JS	#S	#BF	%SF	JS	#S	#BF	%SF	JS
58309 BLK 289 590002 Low temperature	-	-	-	-	6	0	100	0	-	-	-	-
Medium temperature	-	-	-	-	3	0	100	0	-	-	-	-
High temperature	-	-	-	-	Not tested				-	-	-	-
58309 BLK 288 900917 Low temperature	-	-	-	-	3	0	100	0	-	-	-	-
58309 BLK 289 590003 Low temperature	-	-	-	-	3	0	100	0	-	-	-	-

#S = No of samples tested

#BF = No of broken fibers

%SF = Percent of surviving fibers $= \frac{\#S \times 6 - \#BF}{\#S \times 6} \times 100.$

JS = Jacket splits

Table 2.2-9. MM&T Cables - Flexure Test.

Cable	Room Temperature				-55°C				+71°C			
	#S	#BF	%SF	JS	#S	#BF	%SF	JS	#S	#BF	%SF	JS
58309 BLK 289 590002 Low temperature	6	0	100	0	6	0	100	0	6	0	100	0
Medium temperature	6	0	100	0	6	0	100	0	3	0	100	0
High temperature	6	0	100	0	6	0	100	0	3	0	100	0
58309 BLK 288 900917 Low temperature	6	0	100	0	6	0	100	0	3	0	100	0
58309 BLK 289 590003 Low temperature	6	0	100	0	1	0	100	0	3	0	100	0

#S = No of samples tested

#BF = No of broken fibers

%SF = Percent of surviving fibers = $\frac{\#S \times 6 - \#BF}{\#S \times 6} \times 100.$

JS = Jacket splits

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to reduce program cost and it was assumed that test results would not be affected. The test results, however, clearly showed that mechanically strong fibers must be used to meet low temperature mechanical test requirements. As a result of these findings, two cables were made with mechanically strong fibers. One of these cables was made with fibers that were fully qualified for the confirmatory samples phase, and the other cable was made with fibers that were in full compliance with the required 100 kpsi proof-test level but had higher attenuation. The purpose of the last cable, in addition to performing the impact test, was to use this cable to control the payoff tensions of the high speed strander.

2.3.1 Low Temperature Impact Resistance

Table 2.3.1-1 shows the impact resistance at -55°C with 3.0 ft•lb load. There were no fiber breaks or jacket splits. The tests at room temperature and at +71°C were not performed because the previous testing had demonstrated that no failures occurred under those conditions (see Table 2.2-1).

2.4 Optical Evaluation of Cables Jacketed With Estane® 58309

Three cables (040881-4C-2, 050181-4C-1, and 050181-4C-2) were fabricated and extruded with an Estane® 58309 jacket to test the optical requirements of the MM&T-789898 specification. Due to an

Table 2.3.1-1. MM&T Cables - Impact.

3 ft•lb

Cable	Room Temperature				-55°C				+71°C			
	#S	#BF	%SF	JS	#S	#BF	%SF	JS	#S	#BF	%SF	JS
050181-4C-1	-	-	-	-	0	0	100	0	-	-	-	-
050681-4C-2	-	-	-	-	0	0	100	0	-	-	-	-

#S = No of samples tested

#BF = No of broken fibers

%SF = Percent of surviving fibers = $\frac{\#S \times 6 - \#BF}{\#S \times 6} \times 100$

JS = Jacket splits

operator error during the final extrusion process, the length of cable 050181-4C-2 was reduced to 790 m.

Table 2.4-1 shows the attenuation (at 0.85 μm) of cable 040881-4C-2. Two fibers failed to meet the room temperature attenuation requirement (5 dB/km). These fibers were reevaluated; one met the specification and the other showed a marginal increase. The discrepancy between the first and second evaluations was attributed to inaccurate preparation of fiber-ends. The attenuation at -55°C stayed well below 10 dB/km for all fibers.

This cable proves that Estane® 58309 can produce a cable that not only meets the mechanical requirement but also has good optical low temperature performance.

Table 2.4-2 shows the attenuation (at 0.85 μm) of cable 050181-4C-1. One fiber exceeded the 5 dB/km specification by 2.05 dB/km at room temperature. This fiber, however, was found to have a break.

The remaining five fibers had attenuations of lower than 10 dB/km at -55°C. The average increase in attenuation from room temperature to -55°C in cables 040881-4C-2 and 050181-4C-1 was 1.18 dB/km and 1.70 dB/km, respectively.

Table 2.4-1. MM&T Cables - Cable 040881-4C-2.

Attenuation (dB/km)

Fiber Color	Fiber: Room Temp 20 mil	Fiber: -55°C Δ Atten 36.5 mil	Cable: Room Temp	Cable: Reevaluation	Cable: -55°C Δ Atten	Cable: -55°C Atten
Green	3.49	1.58	3.12	-	2.5	5.62
White	3.56	1.40	6.75	3.79	0.82	7.57
Yellow	3.34	0.48	3.68	-	0.45	4.13
Green	4.10	1.81	4.30	-	1.59	5.99
White	3.21	3.74	3.35	-	0.99	4.34
Orange	2.31	2.08	5.11	5.32	0.72	5.83
Avg atten	3.34	1.85	4.35	-	1.18	5.58

Table 2.4-2. MM&T Cables - Cable 050181-4C-1.

Attenuation (dB/km)

Fiber Color	Fiber: Room Temp 20 mil	Fiber: -55°C Δ Atten 36.5 mil	Cable: Room Temp	Cable: -55°C Δ Atten	Cable: -55°C Atten
Red	3.11	1.41	3.34	4.44	7.78
White	3.27	2.20	3.57	1.03	4.60
Blue	3.40	1.54	3.62	1.29	4.91
White	3.27	1.24	3.36	0.71	4.07
White	3.29	1.38	3.27	1.05	4.32
White	3.27	2.57	7.05*	17.63*	*
Avg atten	3.27	1.72	3.43	1.70	5.14

* Fiber broke 696 m from bottom of reel. This fiber is not included in averages.

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Table 2.4-3 shows the attenuation of cable 050181-4C-2. At room temperature, all fibers met the MM&T-789898 specification; however, there was a substantial increase in attenuation at -55°C. The dispersion of cables 040881-4C-2, 050181-4C-1, and 050181-4C-2 is shown in Tables 2.4-4, 2.4-5, and 2.4-6, respectively. Only the yellow fiber of cable 050181-4C-2 exceeds the MM&T specification of 2 ns/km.

Table 2.4-3. MM&T Cables - Cable 050181-4C-2.

Attenuation (dB/km)

Fiber Color	Fiber: Room Temp 20 mil	Fiber: -55°C Δ Atten 36.5 mil	Cable: Room Temp	Cable: -55°C Δ Atten	Cable: -55°C Atten
Red	3.17	4.33	3.26	24.03	27.29
White	3.49	5.31	4.07	7.54	11.59
Blue	3.34	6.78	4.53	31.77	36.30
White	3.82	4.37	4.00	5.39	9.39
White	3.66	5.27	3.94	2.94	6.88
White	3.14	4.98	3.64	2.46	6.10
Avg atten	3.44	5.17	3.91	12.35 (4.58)*	16.26 (8.49)*

*Averages in parentheses do not include the red and blue fibers.

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Table 2.4-4. MM&T Cables - Cable 040881-4C-2.

Fiber Color	Dispersion (ns/km) 0.020" Fiber	0.0365" Cabled Fiber
Green	0.41	0.37
White	1.23	1.30
Yellow	1.07	0.27
Green	0.31	0.94
White	0.41	1.65
Orange	1.39	0.56
Avg dispersion	0.80	0.85

Table 2.4-5. MM&T Cables - Cable 050181-4C-1.

	Dispersion (ns/km)	
Fiber Color	0.020" Fiber	0.0365" Cabled Fiber
Red	0.68	1.15
White	0.42	0.75
Blue	0.96	1.14
White	0.42	1.03
White	0.44	1.24
White	0.42	1.14*
Avg dispersion	0.58	1.06

*Fiber broke 696 m from bottom of reel. It was not included in averages.

Table 2.4-6. MM&T Cables - Cable 050181-4C-2.

	Dispersion (ns/km)	
Fiber Color	0.020" Fiber	0.0365" Cabled Fiber
Green	0.44	0.66
White	0.41	0.43
Yellow	0.44	2.43
Green	0.63	0.89
White	0.45	0.39
Orange	0.42	1.12
Avg dispersion	0.47	0.99

3.0 CABLE MANUFACTURING PROCESS, EQUIPMENT, TOOLING, AND MEASUREMENTS

This section describes the manufacturing process, equipment, and tooling used to manufacture the MM&T cable as well as optical evaluation of cables.

3.1 Cable Manufacturing Process

The basic MM&T cable design is shown in Figure 3.1-1. The cable fabrication flow chart is shown in Figure 3.1-2.

The MM&T cable optical core contains six optical fibers contrahelically laid around a polyurethane coated Kevlar® central member. A jacket of polyurethane is extruded over the optical core. Then the jacketed optical core is served with 18-Kevlar® strength members before a final jacket of polyurethane is applied.

3.1.1 Fiber Rewind Station

This station (Figure 3.1-2, Operation E1) is used to respool and inspect fibers in preparation for the subsequent stranding operation. The equipment consists of a rewinder, an optical lump detector to examine the fiber buffer jacket for any nonuniformities, and a constant-tension compensating payoff to eliminate fiber breaks.

This unit is also used to visually inspect fibers for buffer jacket flaws.

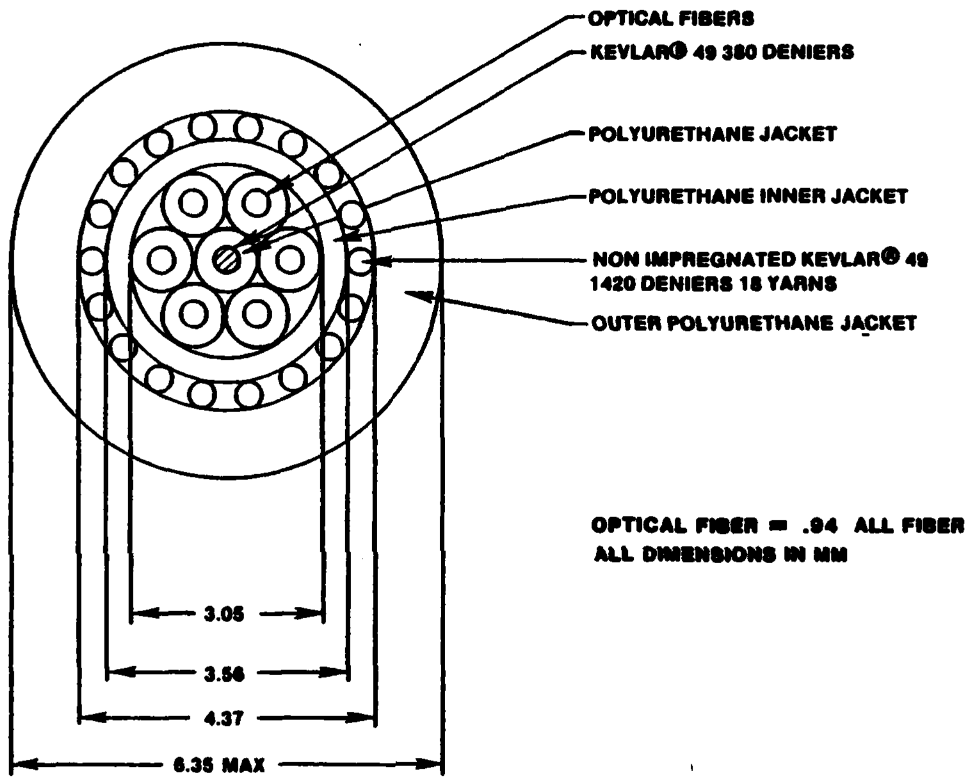

Figure 3.1-1. Basic MM&T Cable Design.

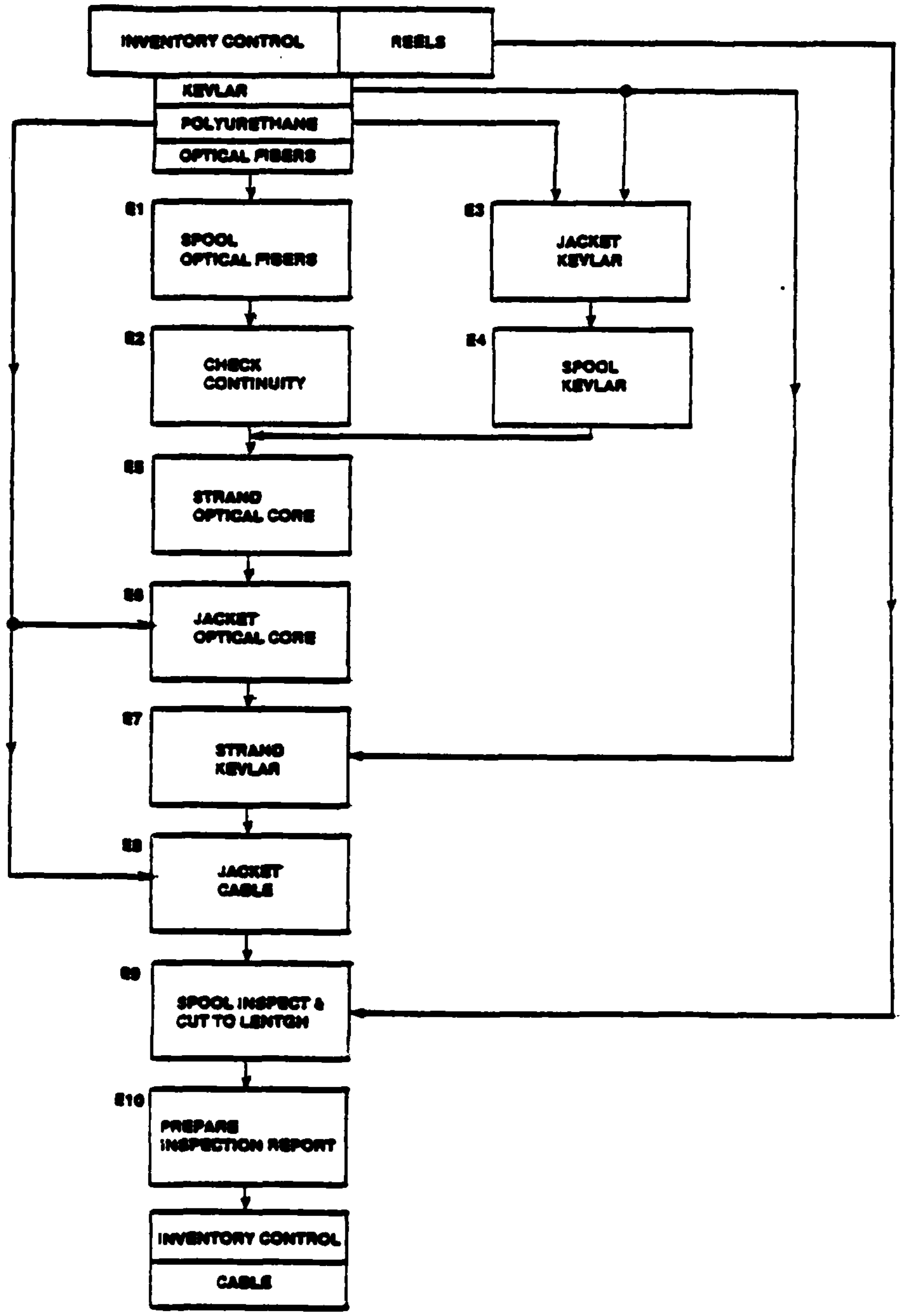

Figure 3.1-2. Cable Fabrication Flow Chart.

3.1.2 Fiber Continuity Check Station

Before fibers are stranded into a cable bundle, continuity of each fiber is tested and any defects or broken fibers are removed. The unit used at this station (Figure 3.1-2, Operation E2) is an instrument designed for detecting and locating faults in optical fibers for measuring their length and for analyzing their transmission characteristics. The instrument operates by launching a pulse of laser light into the fiber and monitoring the amplitude and time delay of events in the light reflected back along the fiber.

3.1.3 Kevlar® Jacketing Station

This station (Figure 3.1-2, Operation E3) is used to overcoat a Kevlar® 49-380 denier yarn with a polyurethane jacket which is used as the central core for the optical bundle. A 1-in extruder is used to pressure extrude the polyurethane jacket at a rate of 76 m/min. An automatic diameter control unit is used which measures the extruded jacket diameter of the core element and regulates the line speed to provide a constant diameter over the existing cable length.

3.1.4 Respooling Station for Polyurethane Jacketed Kevlar® Central Member

The identical equipment as used for the fiber rewind operation (paragraph 3.1.1) is employed. The capacity of this unit is ample to perform both fiber rewind and center member respooling operations.

3.1.5 Optical Core Stranding Station

This station is used (Figure 3.1-2, Operation E5) to strand six optical fibers helically around the polyurethane Kevlar® jacketed center member. A high speed single twist closing unit equipped with a 13-bay neutralizing unit is employed. The unit operates at 1800 m/h.

3.1.6 Optical Core Jacketing Station

Station E6 in Figure 3.1-2 is used to extrude the polyurethane jacket over the optical core. The jacket is applied with a 1-1/2-in extrusion line capable of extruding the first jacket at 68 m/min.

3.1.7 Kevlar® Stranding Station

Station E7 in Figure 3.1-2 is employed to strand 18 Kevlar® strength members around the jacketed optical core. The Kevlar® stranding machine contrahelically serves the 18 Kevlar® strength members around the optical core. The Kevlar® serving line is capable of stranding Kevlar® at 10 m/min.

3.1.8 Final Jacketing Station

A 2-in extrusion line (Figure 3.1-2, Operation E8) is used to extrude the final cable jacket. The extrusion line is capable of extruding the final jacket at 42 m/min which is double the rate required for the MM&T program.

3.1.9 Final Cable Respooling Station

The cable is respooled on the Federal cable rewinder (Figure 3.1-2, Operation E9) for shipping. This machine enables an inspector to visually inspect the cable for anomalies and irregularities while being spooled on the DR-5 reel.

3.2 Optical Evaluation of MM&T Cables

3.2.1 Attenuation Test

The attenuation tests are performed by the cutback method. This procedure is described in the test report for phase 3 MM&T cables in Appendix A. The optical attenuation of each cabled fiber is measured at six selected wavelengths: 8,200; 8,500; 10,600; 11,000; 12,000; and 13,000 Å. All the cable samples are tested to meet the <5 dB/km attenuation requirement.

The calculation procedure followed Method 6020 of MIL-STD-1678. The output through the fiber is measured at 0.82 μm for injection numerical apertures of 0.89, 0.124, 0.176, and 0.243. The attenuation at each of the remaining five wavelengths was measured at an injected NA of 0.089. The single injection NA is selected to avoid changing injection NA conditions at each wavelength thereby eliminating input variation between the short and long length measurements.

Once the output through the long length is measured at the specified wavelengths, the fiber is cut at a distance of 1 m from the injection end. A new end is prepared on the output end of the reference length and the measurement repeated for the short length. The attenuation test setup is shown in Figure 3.2.1-1.

3.2.2 Pulse Dispersion

The MM&T cables are tested for pulse dispersion to determine if the requirement of 2 ns/km maximum is met. The 50% (3 dB) optical pulse dispersion of the test fiber is measured using existing equipment (Figure 3.2.2-1) operating at 9000 Å. Method 6050 of DOD-STD-1678 is utilized.

3.2.3 Numerical Aperture (NA)

The MM&T cables are tested to determine if the NA requirement of >0.17 is met. The exit NA, defined as sin $\phi/2$ where ϕ is the core angle containing 90% of the output power of each cabled fiber, was measured at a wavelength of 0.82 μm. The numerical aperture station is illustrated in Figure 3.2.3-1.

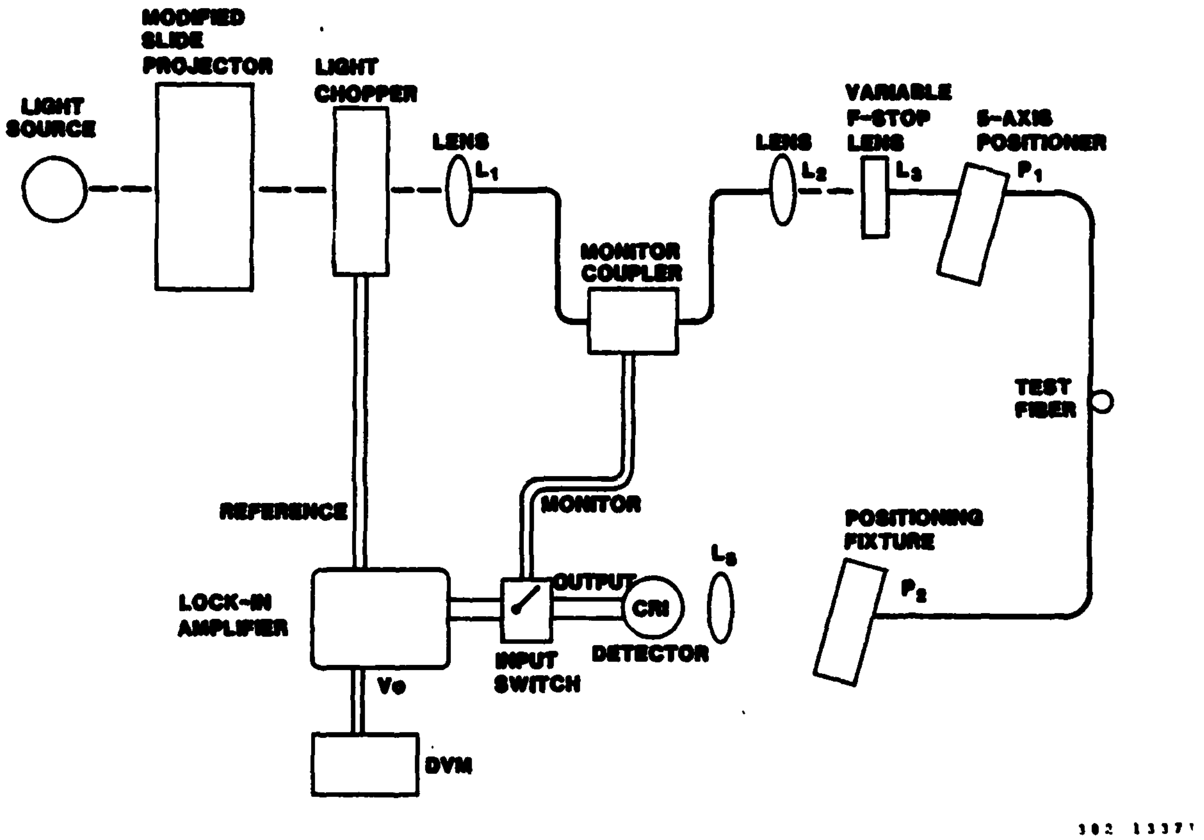

Figure 3.2.1-1. Attenuation Test Setup.

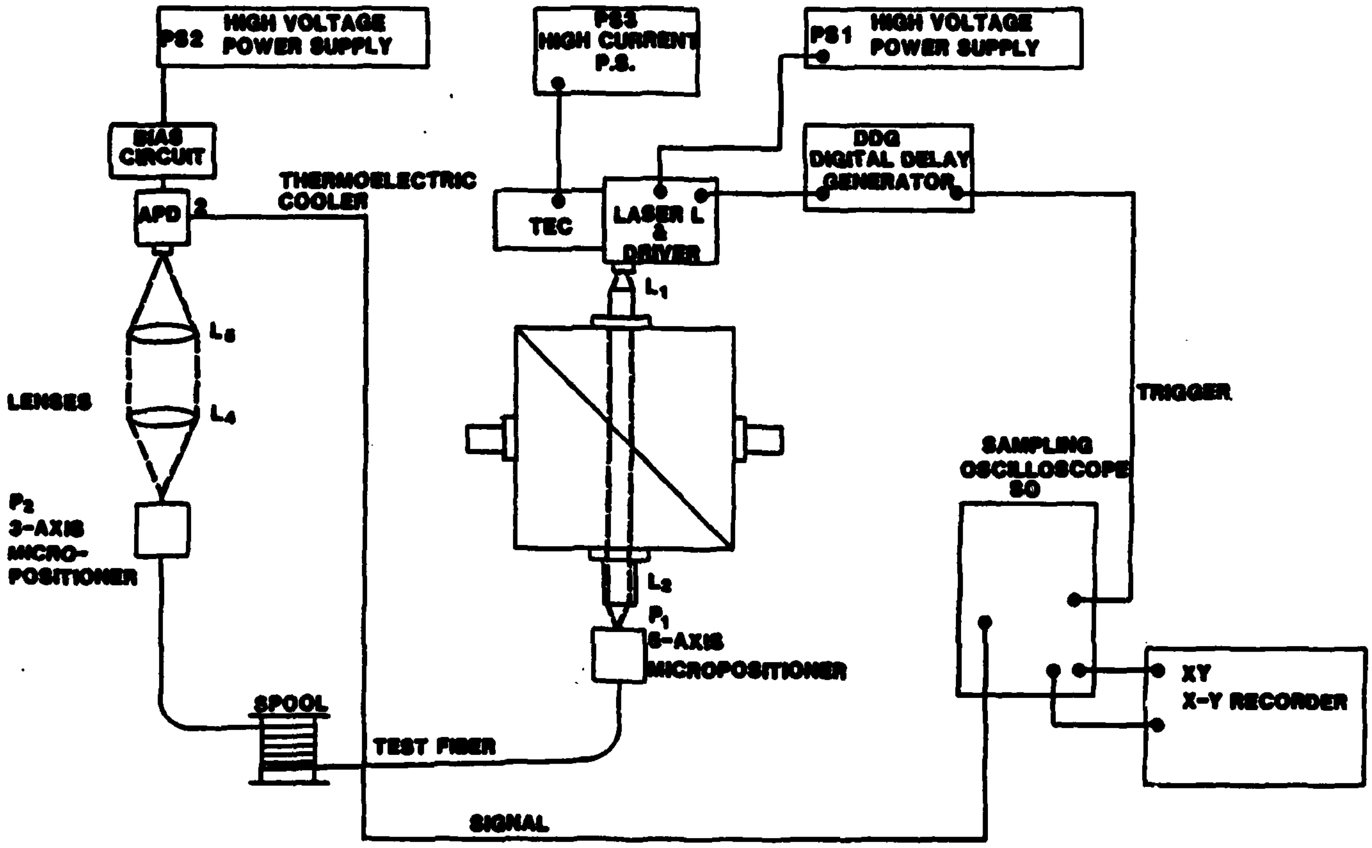

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Figure 3.2.2-1. Pulse Dispersion Test Setup.

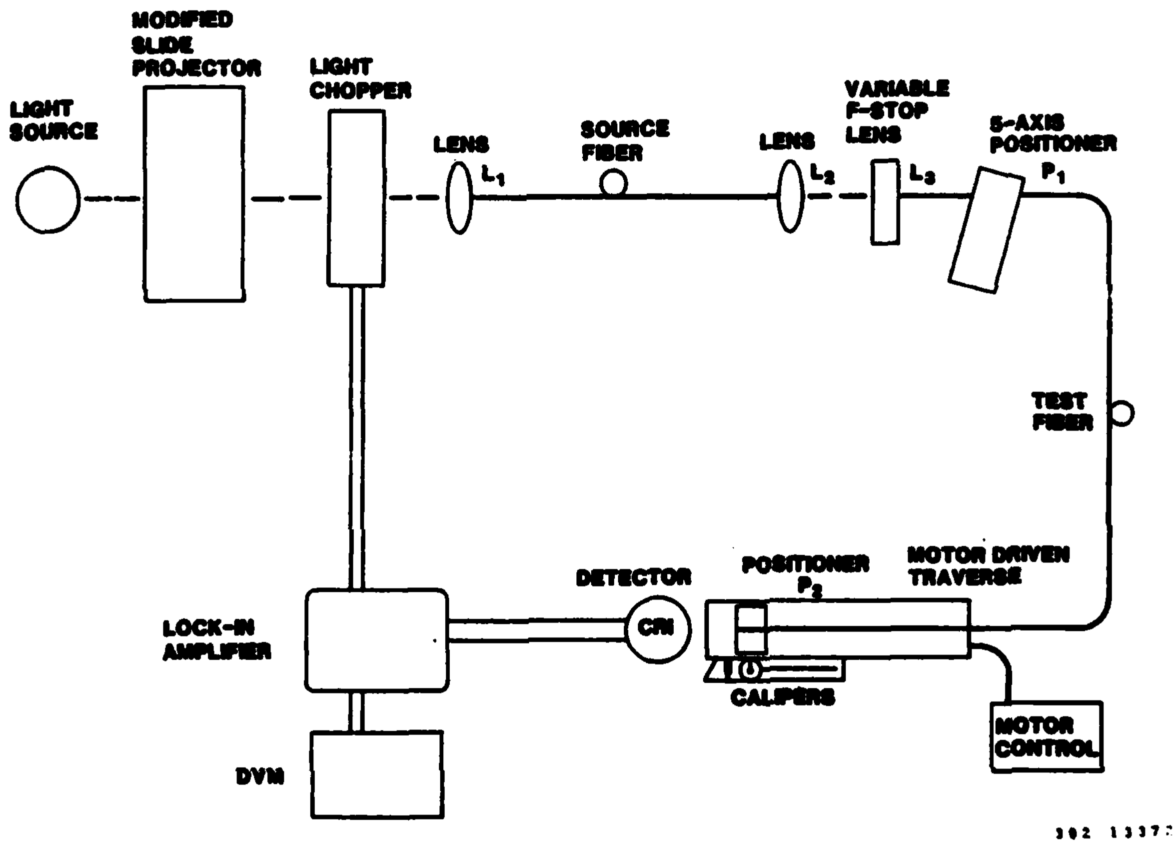

Figure 3.2.3-1. Test Setup for 90% Power Numerical Aperture.

4.0 SUMMARY OF ACCOMPLISHMENTS

The objective of the work performed during this quarter was to select a polyurethane compound that was compatible with the requirements of MM&T-789898. This task was needed because of the change of mechanical properties of Roylar® E-80 when Uniroyal Chemical, Inc., sold its polyurethane product line.

Five short samples of cables with three different lot numbers and three different extrusion temperature profiles were fabricated and evaluated for impact, twist-bend, and flexure resistance at room temperature, at -55°C, and at +71°C. Two long cables were also tested for impact resistance at -55°C. These tests demonstrated that Estane® 58309 BLK-289 meets the mechanical requirements of MM&T-789898.

Three cables were fabricated for optical evaluation (attenuation and dispersion). The attenuation was measured at room temperature and at -55°C. Two of these cables met the -55°C attenuation goal demonstrating that Estane® 58309 BLK-289 does not appreciably affect the optical performance characteristics of fibers at that temperature.

5.0 PERSONNEL

The personnel involved in this program are listed in Table 5.0-1. Due to organizational changes and the changing requirements of the program, the following changes in personnel will be effective for the remainder of the program:

a. T. Osborne was not replaced by F. Akers; he remains as measurements chief

b. A. Asam replaced R. McDevitt in late June

Table 5.0-1. Personnel Working on the MM&T Program.

Name	Task	Man-Hours Expended
R. Coon	Program management	101
J. Smith	Senior project engineer	86
D. Taylor	Cable production management	122
C. Hand	Project coordinator	62

6.0 PROGRAM FOR NEXT QUARTER

The program for the next quarter includes the following objectives:

a. Obtain CECOM approval for Estane® 58309 polyurethane jacketing compound

b. Select optical fibers for 12 confirmatory samples

c. Fabricate 12 confirmatory sample cables

d. Evaluate optically, mechanically, and environmentally the confirmatory samples according to the test plan

e. Submit monthly progress reports

APPENDIX A

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